

High Throughput Laser Processing with Ultra-Short Pulses by High Speed Line-Scanning in Synchronized Mode

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Abstract: Maintaining excellent processing quality with high power ultrafast lasers demands new and fast beam deflecting systems. We present our latest results obtained with a fast polygon line scanner synchronized with a picosecond and femtosecond laser.

OCIS codes: (140.3390) Laser materials processing; (140.7090) Ultrafast Lasers

1. Introduction

High throughput is a key-factor for the industrialization of laser micro machining processes with ultra-short pulsed lasers. According to the two temperature model and for a Gaussian beam the removal rate per average power P_{av} can be expressed as function of the laser peak fluence ϕ_0 [1,2]:

$$\frac{dV}{dt} \cdot \frac{1}{P_{av}} = \frac{1}{2} \cdot \frac{\delta}{\phi_0} \cdot \ln\left(\frac{\phi_0}{\phi_{th}}\right) = \frac{1}{4} \cdot \frac{f}{P_{av}} \cdot \delta \cdot \pi \cdot w_0^2 \cdot \ln^2\left(\frac{2 \cdot P_{av}}{f \cdot \pi \cdot w_0^2 \cdot \phi_{th}}\right) \quad (1)$$

with δ the energy penetration depth, ϕ_{th} the threshold fluence, f the repetition rate of the laser and w_0 the laser beam spot radius.

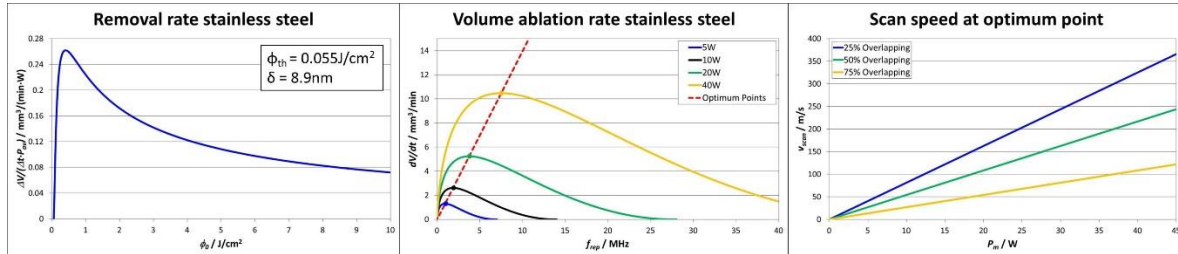


Fig. 1. (left) Removal rate for stainless steel as a function of peak fluence; (center) volume ablation rate for stainless steel for different average powers as a function of the repetition rate; (right) Influence of the average power onto the scan speed for different pulse overlaps.

Fig. 1 shows the removal rate for stainless steel as a function of the applied laser peak fluence (left) or the repetition rate (center) for a spot radius of about 30 μm and different constant average powers. It is obvious that there exist an optimum point going with a maximum removal rate. A short calculation leads to [1,2]:

$$\phi_{0,opt} = e^2 \cdot \phi_{th} \quad \text{and} \quad \left. \frac{dV}{dt} \right|_{P_{av}} \bigg|_{max} = \frac{2}{e^2} \cdot \frac{\delta}{\phi_{th}} \quad (2)$$

Following (2) the removal rate linearly scales with the average power when one works at the optimum point with the fluence $\phi_{0,opt}$ i.e. to obtain high throughput, the average power of the laser system has to be increased by either increasing the pulse energy or the repetition rate. Due to the optimum fluence which has to be kept, the former demands larger focal spots or parallelization as e.g. shown in [3,4] and the latter high marking speeds. Following (2) the marking speed as a function of the overlap o is given by:

$$v = \frac{4}{\pi \cdot e^2} \cdot \frac{(1-o) \cdot P_{av}}{w_0 \cdot \phi_{th}} \quad (3)$$

For a high machining quality a pulse overlap between 50% and 75% should be chosen [5] leading to high marking speeds as shown Fig. 1 (right) for a spot radius of about 30 μm . Even for a moderate average power the demanded marking speed exceeds 50 m/s, a value which is far above the limits of conventional galvo scanners.

2. Set-Up

Such high speeds can be offered by a polygon line scanner as e.g. by the LSE170A from Next Scan Technology. This scanner system was used in combination with a FUEGO ps- and a SATSUMA fs laser. Further, the laser and

was synchronized to the scanner via the Supersync™ technology to achieve highest precision [5]. All experiments were performed for 1064 nm (ps pulses) and 1030 nm (fs pulses) with a spot radius of about 30 μm . The movement perpendicular to the scan direction of the polygon was realized with a linear axes slaved to the controller of the polygon.

3. Results

The position accuracy and the repeatability were deduced for different scanning speeds from 25 m/s up to 100 m/s. It was found that the repeatability is within $\pm 1 \mu\text{m}$ whereas the position accuracy increases with higher marking speed. In the case of stainless steel 1.4301 (in US: AISI 304) micromachining up to 43 W of average power and 8.2 MHz repetition rate was investigated. It was found that the removal rate per average power rests constant for repetition rates up to 300 kHz and drops, due to particle shielding [6], by about 25% when the repetition rate is raised to about 2 MHz. For even higher repetition rates the removal rate slightly increases due to heat accumulation.

Concerning the machining quality two main problems have been encountered: First the gating module of the ps-laser can only deliver single pulses up to a repetition rate of about 2.5 MHz, afterwards pre- and post-pulses will have an influence onto the ablation process leading to an enlarged minimum spot size in the scanning direction. Second, the pyramidal error (this error describes the angle error from facet to facet due to fabrication tolerances) leads to a wavy surface with a variation of more than 2 μm if multi layers are ablated. Especially for these multi-layer applications a strategy, which averages the pyramidal error, was developed and successfully tested. As an example the topography of Switzerland (fig. 2) was machined into steel with a pitch of 14.5 μm , a marking speed of about 60 m/s, an average power of 26 W, a repetition rate of 4.1 MHz and 2233 layers. The final dimensions were 107.7 mm x 65.5 mm with a maximum depth of about 115 μm .

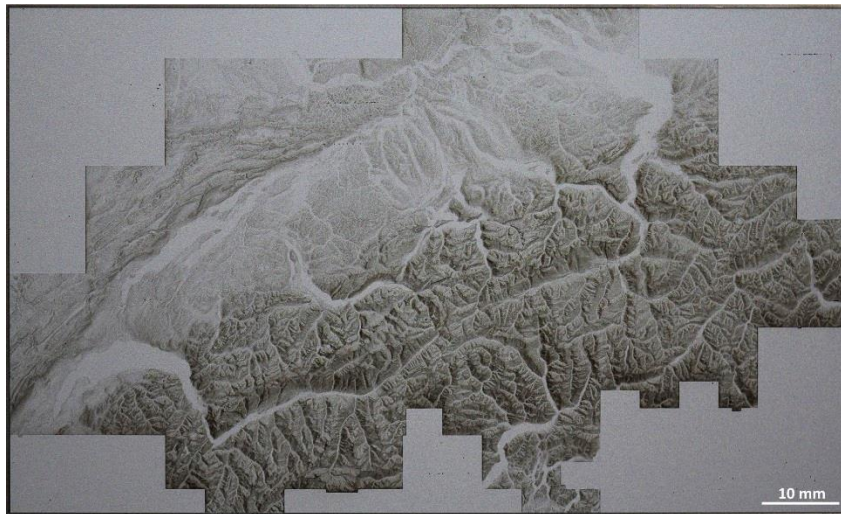


Fig. 2: Topography of Switzerland machined into stainless steel.

5. References

- [1] G. Raciukaitis, M. Brikas, P. Gecys, B. Voisiat, M. Gedvilas, M., "Use of High Repetition Rate and High Power Lasers in Microfabrication: How to keep Efficiency High?", *JLMN* **4**, 186-191 (2009)
- [2] B. Neuenschwander, G. Bucher, C. Nussbaum, B. Joss, M. Mural, S. Zehnder, "Processing of dielectric materials and metals with ps laserpulses", *ICALEO Conference Proceedings*, Paper M101 (2010)
- [3] O. Haupt, V. Schuetz, U. Stute, "Multi-Spot Laser Processing of Crystalline Solar Cells", *Proceedings of SPIE* **7921** (2011)
- [4] M. Silvennoinen, J. Kaakkunen, J. Paivasaari, "Parallel microstructuring using femtosecond laser and spatial light modulator", *Physics Procedia* **41**, 693-697 (2013)
- [5] B. Jaeggi, B. Neuenschwander, U. Hunziker, J. Zuercher, T. Meier, M. Zimmermann, K.H. Selbmann, G. Hennig, "Ultra high precision surface structuring by synchronizing a galvo scanner with an ultra short pulsed laser system in MOPA arrangement", *Proceedings of SPIE* **8243** (2012)
- [6] J. Koenig et al, "Plasma evolution during metal ablation with ultrashort laser pulses", *Optics Express* **13**, 10597-10607 (2005)